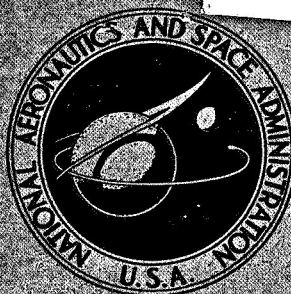


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A TWO-DIMENSIONAL AND AN AXISYMMETRIC  
SUPERSONIC INLET SYSTEM (NASA) 18 p

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**PERFORMANCE SUMMARY  
OF A TWO-DIMENSIONAL  
AND AN AXISYMMETRIC  
SUPERSONIC-INLET SYSTEM**

U. S. Government Agencies and  
Contractors Only

*by Norman E. Sorensen, Warren E. Anderson, Norman D. Wong,  
and Donald B. Smeltzer*

*Ames Research Center  
Moffett Field, Calif.*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1966

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PERFORMANCE SUMMARY OF A TWO-DIMENSIONAL AND AN  
AXISYMMETRIC SUPERSONIC-INLET SYSTEM\*†

By Norman E. Sorensen, Warren E. Anderson,  
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SUMMARY

X66-23289

The results of approximately three years of theoretical and experimental research effort are summarized for a large-scale two-dimensional and axisymmetric inlet system. A series of wind-tunnel tests have provided a background of experimental information showing the performance capabilities at Mach numbers from 0.6 to 3.2. The primary objectives were to investigate relatively short mixed-compression inlet systems with low external drag and to achieve high performance over the complete Mach number range with a minimum of engine-face distortion. The main conclusions are that the supersonic portion of the inlet system performed as predicted, and that the main difficulty in achieving high performance lay in the throat and subsonic diffuser. In addition, short subsonic diffusers appear practical when vortex generators are employed downstream of the throat.

*Conf.*

*Author*

INTRODUCTION

Air-induction system research and development programs at Ames Research Center have primarily supported the supersonic transport. The results, however, have a wide range of application to other supersonic aircraft. A series of wind-tunnel tests for large-scale two-dimensional and axisymmetric inlet systems have provided a background of experimental information showing the performance capabilities over most of the Mach number range up to 3.0. The present paper is intended as a brief summary of the results of approximately three years of theoretical and experimental research effort.

The programs were conceived to attain three major objectives.. The first objective was to investigate mixed-compression inlet systems that were relatively short and had low external drag in an attempt to minimize the weight and drag while maintaining high internal performance. The second objective was to achieve high internal performance over the complete Mach number range, insuring maximum vehicle performance not only during cruise, but also during climb and acceleration. Because the engine-face distortion of short inlet systems is usually large, or unacceptable, the third objective was to investigate means for controlling the distortion to within acceptable levels.

Satisfactory performance of the supersonic transport has demanded propulsion systems with light-weight high-performance inlets. This has led to rather sophisticated designs which employ high internal contraction supersonic

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†Presented at NASA Conference on Aircraft Aerodynamics, Langley Research Center, May 23-25, 1966.

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differentially actuated for optimization of the area variation in the throat region. The angle of the initial ramp compression surface is fixed at  $7^\circ$ . The lower cowl surface can be translated aft, to the position indicated, for operation at Mach numbers lower than about 1.75. This translation provides for efficient external compression and spillage at low off-design Mach numbers. Perforated ramp and side-wall surfaces allow the boundary layer to bleed into three compartmented zones located above the ramps and then through ducts to controllable exit plugs. Bleed flows from the cowl and forward side wall are dumped directly to the outside airstream. Total pressure rakes are located at the simulated engine face. Vortex generators, which will be discussed subsequently, have been located in the throat region on the ramp and cowl surfaces, with eight on the cowl and eight on the ramp. The detailed design of the vortex generators follows the procedures of reference 1.

Initial tests were completed on the short subsonic diffuser, which represents an equivalent conical angle of about  $9^\circ$ . The maximum turning angle of the ramp surface was  $25^\circ$ . Design modifications, shown by the dashed lines, resulted in a subsonic diffuser which is equivalent to a  $7^\circ$  conical angle. With a slight increase in length, the ramp turning rates were reduced to a maximum of  $16^\circ$ .

Even though the off-design performance is important, the design performance is usually more important. Figure 4 indicates the supercritical performance at Mach number 3.0 and zero angle of attack and sideslip. Engine-face pressure recovery and distortion are plotted as a function of boundary-layer-bleed mass-flow ratio. The more usual abscissa for a supercritical plot is engine-face mass-flow ratio, which is merely the difference between 1 and the boundary-layer-bleed mass-flow ratio.

Initial tests of the two-dimensional inlet model utilizing the short subsonic diffuser indicated that flow along the ramp surface in the subsonic diffuser was separated. A total-pressure recovery of 87 percent was achieved with a bleed mass-flow ratio of about 13 percent with about 17-percent distortion. The modified system, as mentioned previously, had a subsonic diffuser with reduced turning angles on the ramp surface. The modification resulted in a peak pressure recovery of about 88 percent with about 14-percent bleed, but the distortion levels were high, 12 to 16 percent, because of flow separation on the subsonic ramp surface similar to that experienced with the shorter diffuser. Since a distortion of 10 percent is considered a nominal maximum, the forced mixing principle employing vortex generators was investigated for reducing the distortion. The test results show that adding four pairs of vortex generators across the width of the ramp side eliminated separated flow and reduced the distortion to 8 percent with a peak recovery of 90 percent. Placing vortex generators on both the cowl and ramp further reduced the distortion to 5 percent but increased mixing losses in the flow near the cowl surface, and resulted in a slight decrease in the maximum attainable recovery. The bleed mass-flow ratio for the bleed configuration used in this series of tests increased from about 11.5 percent to about 14.5 percent as a result of the terminal shock wave moving over the porous bleed surfaces in the throat. The dashed line is the envelope of peak performance for other bleed configurations. To avoid confusion the supercritical performance for all configurations was



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The effect of vortex generators on engine-face distortion is further clarified in figure 5. This slide presents total-pressure ratio profiles at the engine face, measured by a vertical center-line rake, for the peak recovery conditions of the previous figure. Without vortex generators the profiles for both the short and modified inlet are highly distorted. Adding vortex generators on the ramp side eliminated separation and improved the profile mostly near the ramp side, leaving the distortion near the cowl side much as it was. The addition of generators on the cowl side improved the profile to the point where the distortion was reduced to about 5 percent. The vortex generator tests were limited, and further improvements might be possible.

The performance at angles of attack and sideslip has shown some interesting results. Figure 6 shows the peak pressure recoveries at Mach numbers 3.0 and 2.5 for the short and modified inlets. As is expected the peak recovery at angle of attack is different from the recovery at angle of sideslip, the latter, shown by the dashed curves, having the lower recoveries. Two interesting results are to be noted. One is that the difference in recovery at angle of attack and sideslip is considerably greater at Mach number 3.0 than at 2.5. The other point is that the inlet with the short subsonic diffuser performs about as well as the one with the modified diffuser at Mach number 2.5, but is considerably poorer at Mach number 3.0 by 3 to 6 percent. This appears to be a result of the previously mentioned separated flow in the subsonic diffuser which persists or is aggravated with increase in angle of attack and sideslip. At Mach number 2.5 or less the flow is attached. This accounts for the better results shown for Mach number 2.5.

The final data plot for the two-dimensional inlet is shown in figure 7. Pressure recovery and distortion for peak operating conditions are plotted for a range of Mach numbers from 0.6 to 3.0. A break in the curves occurs at a Mach number of 1.3 because of test facility restrictions which limited boundary-layer bleed to about 2 percent at the transonic Mach numbers. At the higher Mach numbers from 1.55 to 3.0 the bleed varied from about 7 to 14 percent. Note that the cowl was retracted for Mach numbers below 1.75 and the inlet operated as an all external compression system, which probably accounts for the change in trend of the distortion in this Mach number range. The use of vortex generators on the ramp reduced distortion about 2 to 4 percent throughout the Mach number range without significantly affecting engine-face pressure recovery. A similar effect will be shown later for the axisymmetric inlet.

## AXISYMMETRIC RESULTS

Figure 8 shows quarter section sketches of three of the inlet systems that have been tested. The upper quarter section shows two of the systems while the lower section shows the third system. In the upper quarter section one system is a rather long 1.86 diameter system measured from the lip to the engine face;





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**1**





is about 1.2. With higher throat Mach numbers more tolerance is expected. It should be noted that the performance indicated at the operating points does not represent the performance at the unstart angles of attack. The performance is always something less at angle of attack. This is shown in figure 11 where comparable peak recoveries and the distortion are plotted as functions of flow angle for the three inlet systems. Each system exhibits its own peculiarities and a trend is not clear from the results. The short inlet, for instance, produces the highest recovery at  $5^\circ$  and  $8^\circ$ , a result which one might not expect. In addition, the distortion, even though it is high, is no worse than the medium length inlet at these same angles, and perhaps the generally lower distortion of the long inlet can be attributable to its longer length. The recovery for the short inlet, however, drops more rapidly from  $0^\circ$  to  $2^\circ$  than either of the other two systems sharing the same supersonic diffuser. This would seem to indicate the supersonic diffuser has an important influence on the angle-of-attack performance.

The three inlet systems have performed well over the complete Mach number range. Critical recovery and the accompanying distortion are shown in figure 12 to be comparable from Mach number 0.6 to 3.2. The results from Mach number 0.6 to 1.2 are optimum for a selected turbofan engine; that is, the net thrust minus the additive drag has been optimized to provide realistic as well as comparable results. The long and medium systems have shown about the same recovery capabilities but the distortion of the medium length inlet is generally lower. This indicates that the vortex generators are effective throughout the Mach number range even when (at other than the design Mach number) they are much displaced from the design position in which the cowl and centerbody generators are opposite one another. The short inlet shows a similar trend of recovery but at several percent increase at the higher Mach numbers. The distortion is generally lower than that of the long inlet. The peculiar dip in recovery at Mach number 2.9 for the short inlet is difficult to explain. This was not detected in the tests of the other two configurations but may also have been present. The points at  $M_\infty = 3.2$  are overspeed conditions for the inlets; that is, the results at  $M_\infty = 3.2$  were obtained with the Mach number 3.0 geometry settings, which accounts for the rapid deterioration of the distortion and recovery.

#### CONCLUDING REMARKS

The main conclusions to be drawn from the present summary for the two-dimensional and axisymmetric inlet systems are that the supersonic portion of the inlet systems performed as predicted, and that the main difficulty in achieving high performance lay in the proper design of the throat and subsonic diffuser. Also, short subsonic diffusers appear feasible when vortex generators are employed downstream of the throat. In addition, it appears that in

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order to achieve the highest performance a nearly isentropic supersonic diffuser must be employed which requires complete contouring of both the cowl and centerbody.

Ames Research Center  
National Aeronautics and Space Administration  
Moffett Field, Calif., May 23, 1966  
720-03-01-01-00

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- $$m = \frac{1}{2}$$



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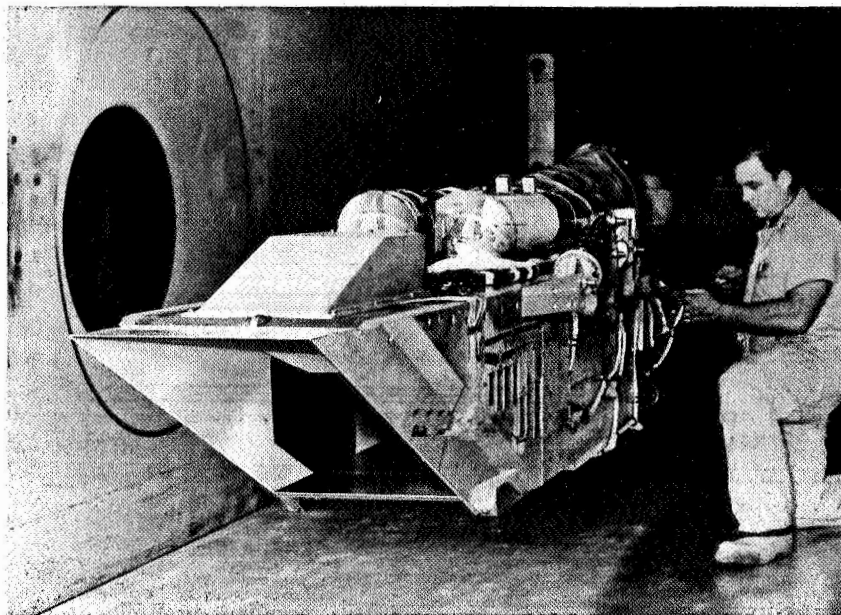


Figure 1.- Two-dimensional inlet model. A-32238.1

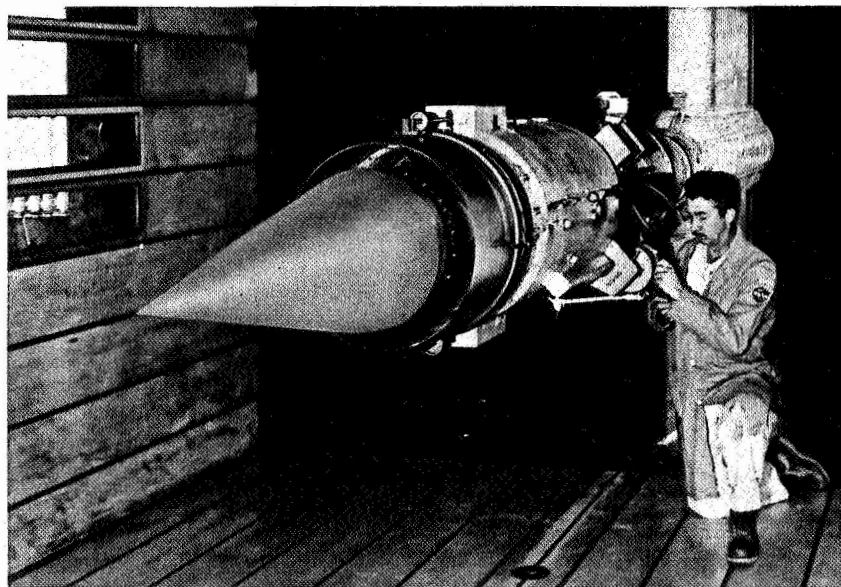


Figure 2.- Axisymmetric inlet model. A-34092.1

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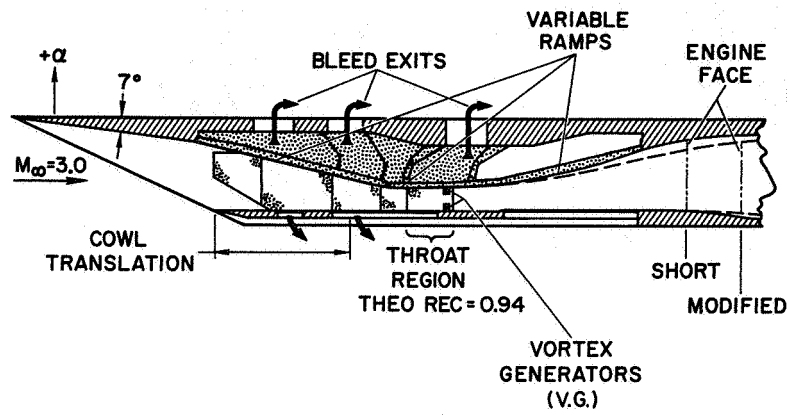


Figure 3.- Two-dimensional inlets.

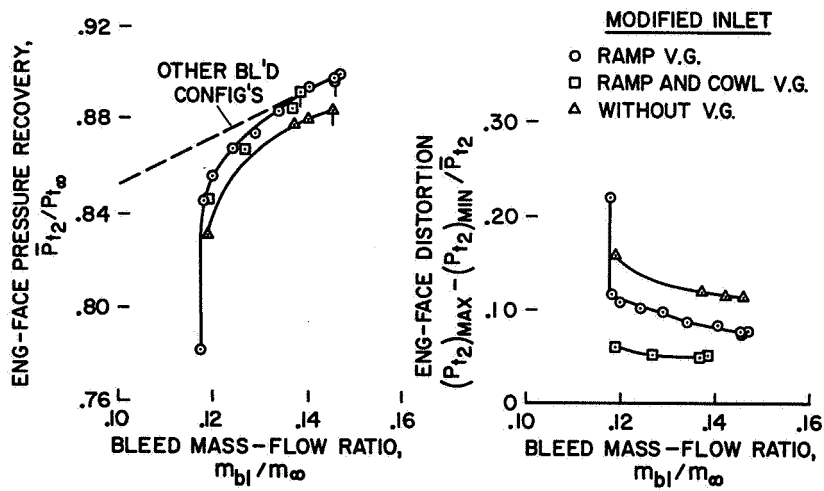


Figure 4.- Two-dimensional inlets, supercritical performance;  $M_\infty = 3$ ,  $\alpha = \beta = 0^\circ$ .



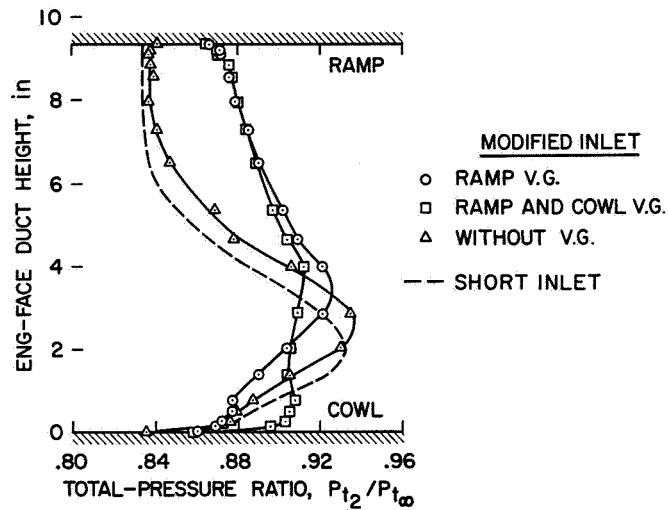


Figure 5.- Two-dimensional inlets, effect of vortex generators;  $M_{\infty} = 3$ ,  $\alpha = \beta = 0^\circ$ .

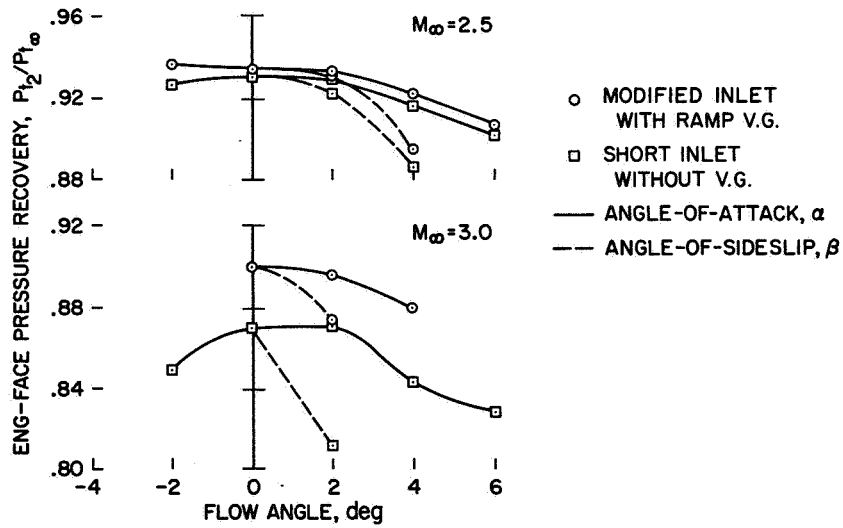


Figure 6.- Two-dimensional inlets, peak performance with flow angle;  $M_{\infty} = 2.5$ .

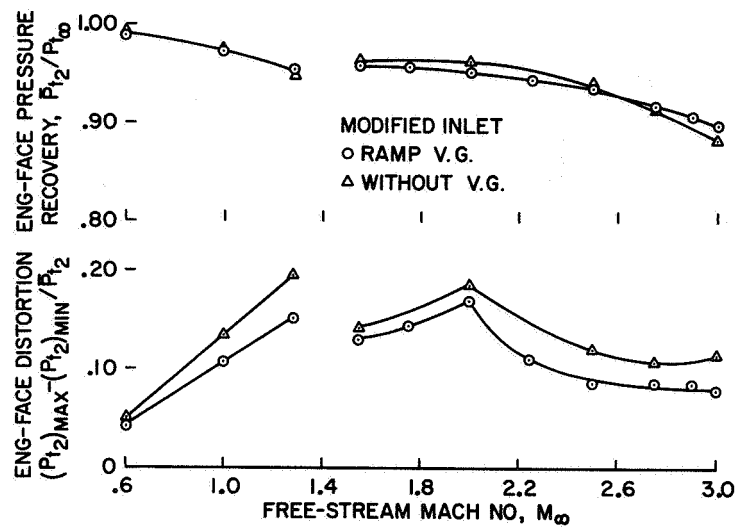


Figure 7.- Two-dimensional inlets, off-design performance;  $\alpha = \beta = 0^\circ$ .

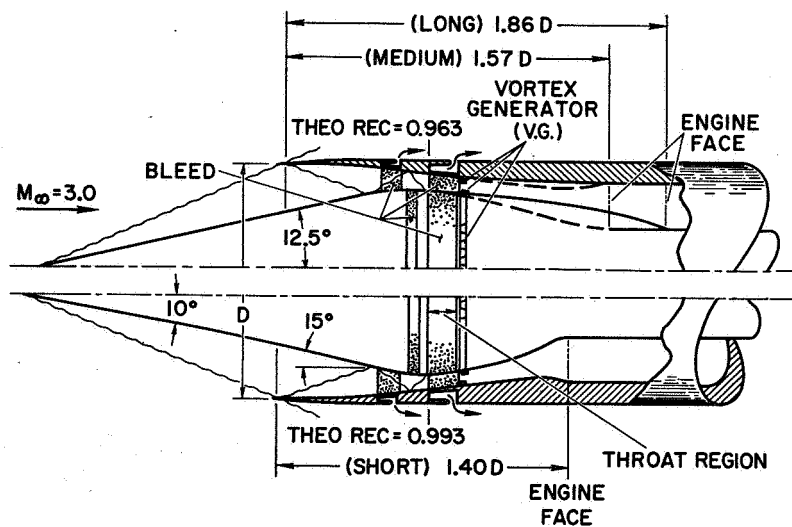


Figure 8.- Axisymmetric inlets.

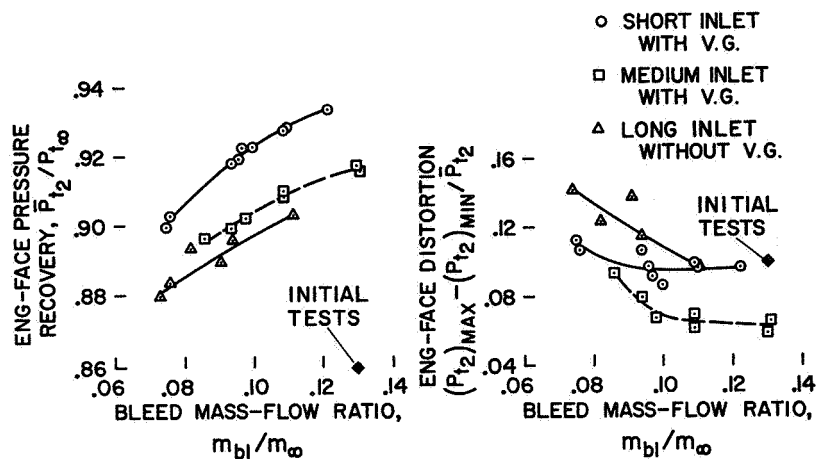


Figure 9.- Axisymmetric inlets, peak performance;  $M_{\infty} = 3$ ,  $\alpha = 0^{\circ}$ .

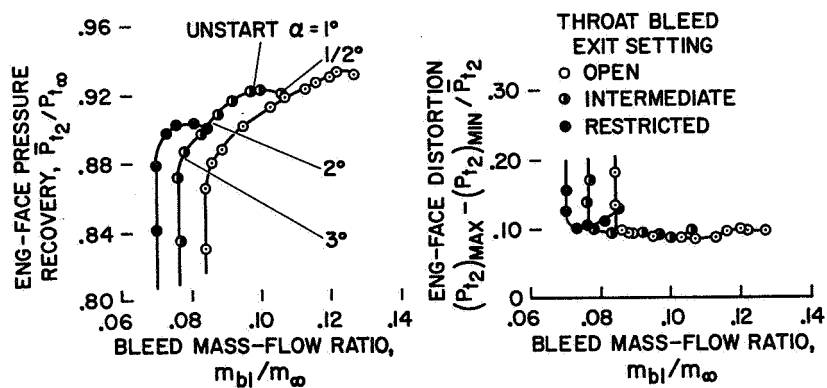


Figure 10.- Short axisymmetric inlets, supercritical performance;  $M_{\infty} = 3$ ,  $\alpha = 0^{\circ}$ .

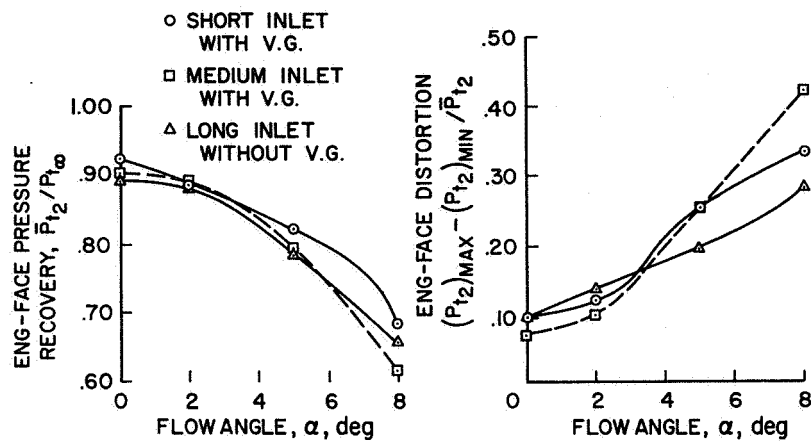


Figure 11.- Axisymmetric inlets, peak performance with flow angle;  $M_\infty = 3$ .

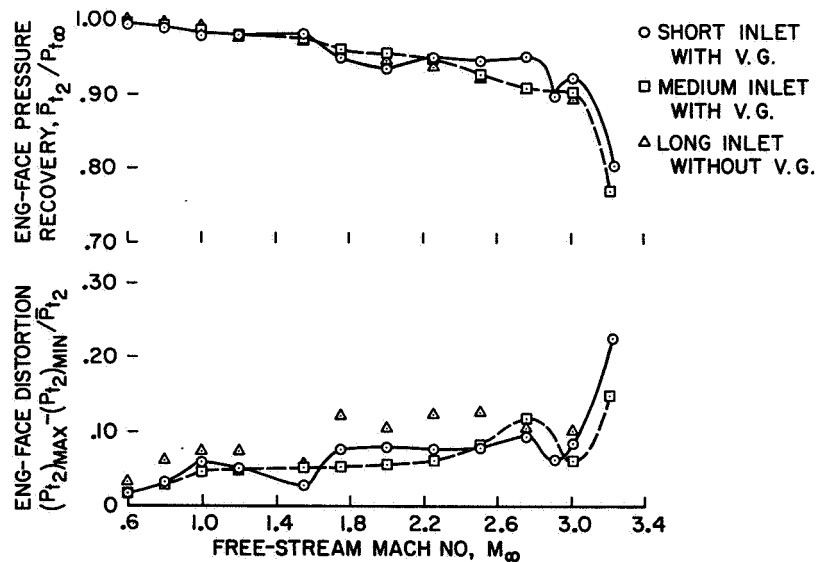


Figure 12.- Axisymmetric inlets, off-design performance;  $\alpha = 0^\circ$ .